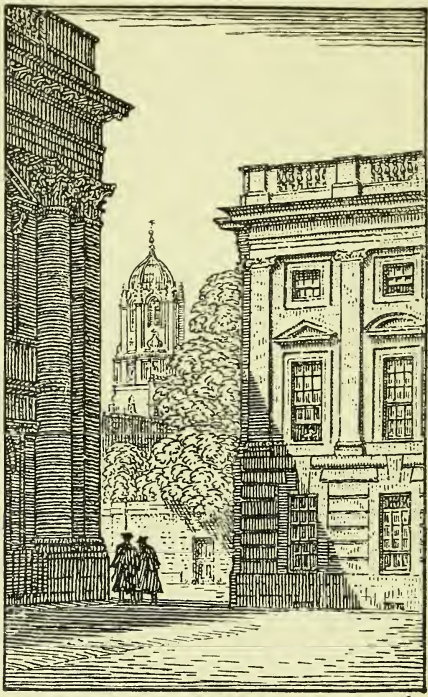


COLL. REG. MED. LOND.
MDXVIII
Ο ΒΙΟϹ
ΤΕΧΝΗ
ΒΡΑΧΥϹ Η
ΔΕ
ΜΑΚΡΗ

THE NEBULÆ:

A FRAGMENT

OF

ASTRONOMICAL HISTORY.

BY

ARCHIBALD E. GARROD, B.A.

Parker and Co.

OXFORD, AND 6 SOUTHAMPTON-STREET, STRAND,

LONDON.

1882.

The following pages contain the substance of the Johnson Memorial Prize Essay (University of Oxford) of 1879, *reconstructed and rewritten in* 1881.

THE NEBULÆ.

CHAPTER I.

Sir William Herschel's Observations.

In these days of rapid scientific progress there is a tendency to accept the facts of nature, as at present known, without glancing back at the slow and difficult stages by which the knowledge of these facts has been arrived at. Yet such a retrospect is by no means unprofitable, since it warns us that hasty generalizations upon insufficient data retard rather than advance the progress of knowledge, and that the theories of the day must not be accepted as necessarily expressing absolute truths.

From this point of view few chapters in the history of Natural Science possess greater interest than that which deals with nebulæ and star-clusters. During a careful telescopic examination of the heavens, besides single and double stars, and clusters of different degrees of condensation, we meet with certain faintly-luminous areas, which have received the name of Nebulæ. Many of the objects formerly included under this name have been shewn by increased optical power to be merely very compact star-clusters. There remain, however, many, usually of a blue or green tint, which have never been so resolved. They vary greatly in size, from the great nebula in the sword-handle of Orion, which is visible to the naked eye, to the small planetary nebulæ which require for their observation the highest powers of the telescope.

The extreme faintness of these objects rendered their discovery impossible, with a few exceptions, until the telescope had made considerable advance towards its present state of perfection, and a more detailed study of them is now only possible with the most powerful instruments.

Two theories of the nature of the nebulæ have been advanced, one of which regards them as merely very remote star-clusters, which by reason of their enormous distance appear so faint and ill-defined; the other as vast areas of phosphorescent matter or incandescent gas.

Now the one, now the other of these views has met with general adoption by the astronomical world, and in the present sketch it will be our endeavour to trace the various phases of opinion, starting from the time when Sir William Herschel first made these objects the subject of his researches.

We shall see that Herschel, finding that his powerful telescope was able to distinguish the starry points composing many, till then, unresolved nebulæ, was at first led to conclude that all nebulæ would eventually yield to increased optical power, thus rejecting the theory of a nebulous matter, which had previously been held as a vague hypothesis by Kant, Tycho Brahe, and others.

Further researches led him to modify his opinions, owing to the difficulty which he found in reconciling it with certain observed phenomena, and in the theory of "Sidereal Aggregation" which he afterwards propounded we have, in an accurate form, a further development of the notions of the earlier astronomers.

We shall find, however, that Herschel's later views did not meet with the acceptance of his immediate successors, and there is perceptible a gradual drifting back to his earlier view, that all nebulæ are of a starry nature, until this theory became firmly established in the minds of Sir John Herschel and his contemporaries by a line of argument identical with that which had led to its adoption on the previous occasion, for still greater optical power was found to reduce still more the number of unresolved nebulæ.

Yet this view was before long again found to be insufficient to explain all the observed facts, especially the phenomena of variable nebulæ, and the astronomical world was not wholly unprepared for Mr. Huggins' discovery, in 1864, that the spectra of many nebulæ are such as can only be yielded by incandescent gases.

The knowledge of the subject previous to Herschel's first paper was small. Simon Marius had discovered the nebula in Andromeda in 1612, and Huyghens that in Orion in 1656.

The idea that stars might be formed by the condensation of a nebulous matter was originated by Tycho Brahe, and by such a condensation of a portion of the milky way, at that time unresolved, he endeavoured to account for the appearance of a bright new star in 1572.

Kepler advanced a similar explanation of the new star of 1604, but found difficulty in reconciling this view with the absence of change in the configuration of the galaxy.

The most ardent supporters of this hypothesis of the origin of stars, during the eighteenth century, were Kant and Lambert, and its most vigorous opponents Cassini and Mitchell.

In 1771 [a] Messier collected into a catalogue the then known nebulæ, 103 in number, many of which he had himself discovered, whilst others had been observed by Lacaille, who had done good work upon the subject at the Cape of Good Hope.

Sir William Herschel's [b] powerful telescope gave him great advantages over his predecessors, and the list of known nebulæ soon swelled from 103 to 2,000. He moreover systematized his observations, and elaborated the theory of sidereal aggregation, which traced in the various forms of nebulæ and clusters the working out of mighty cosmical laws, the birth, the growth, and the decay of starry systems. His earliest observations revealed a stratified arrangement of these objects in space, a zone of nebulæ appearing to surround the heavens at right angles to the milky way. These nebulous regions were found to be preceded and followed by tracts singularly free from stars, so much so as frequently to afford a field of view unbroken by a single starry point. This rule was found to be so constant, that when the telescope in its diurnal motion entered upon a region very poor in stars, Herschel was in the habit of

[a] *Mem. Acad. Sci.*, 1771. *Enlarged, Connaissances des Temps*, 1783 and 1784.

[b] *On the Construction of the Heavens. Phil. Trans.*, 1784, p. 439.

warning his assistants to be prepared to record observations, as he was on the borders of a nebulous region.

We have mentioned before that the number of hitherto unresolved nebulæ which his telescope shewed to be true star-clusters, led Herschel to infer that all nebulæ were actually more or less distant clusters, and he soon endeavoured to frame a theory of their formation [c].

Starting with an approximately equal distribution of stars in space subject to gravity, it is evident that a star of greater mass than the surrounding stars would tend to exercise a preponderating attraction upon its neighbours, a globular cluster being formed with the large star as its centre. Other clusters would be formed around a group of several stars, the centre being in this case merely a centre of force. This would account for the large number of globular clusters; for that the clusters which present to us a circular disc are really globular cannot well be doubted [d], since the probability that in so many instances a cone or cylinder should present its circular end to the earth is infinitely small. Clusters of other forms might arise from condensation around variously-shaped central groups.

Amongst Nebulæ are certain objects to which the term "planetary" is applied. The light of these objects has a blue tint, and their evenly-illuminated surfaces shew no sign of central condensation, which renders it hard, if not impossible, to reconcile their appearance with a starry nature. We are accordingly not surprised to find that of all their class these objects have afforded most ground for speculation. The hypotheses which have been advanced are numerous, and in his paper of 1785, Herschel suggests that they are perhaps composed of suns which, "by some decay or waste of nature being no longer fit for their former purposes, have rushed together at last, and either in succession, or in one general tremendous shock, may have united into a new body."

The result of such a catastrophe would be very different to that which is here depicted, for the law of the Conservation of Energy teaches us that the energy of motion of

[c] *Phil. Trans.*, 1785, p. 213. [d] *Ibid.*, 1789, p. 212.

the individual stars would be in the most part converted into the energy of heat, which would dissipate in the gaseous form the clashing globes, for it has been calculated that the earth alone falling into the sun would generate sufficient heat to supply the solar radiation, at its present rate, for fourteen years.

Herschel saw in the various forms of clusters the successive stages of their development, and was able on this hypothesis to extend his observations over an immeasurable period, for, as he says,—

"Is it not the same thing whether we live successively to witness the germination, blowing, foliage, fecundity, fading, withering, and corruption of a plant, or whether a number of specimens selected from every stage through which a plant passes in the course of its existence are presented at once to our view?"

Whilst thus employed in studying the grouping of stars, the great astronomer had not neglected to search the heavens with a view to fresh discoveries, and in 1786[e] and 1789 he published two catalogues, each containing 1,000 new nebulæ and clusters.

It was during the next two years, 1789—1791, that Herschel began to realize the insufficiency of the stellar theory, and this change in his opinions seems to have been chiefly the result of his observations of the "nebulous stars properly so called[f]." The objects included under this name are not the nebulous stars of earlier observers, which increase of optical power had shewn to be merely clusters with central condensation, but faintly-luminous discs, in the centre of which a star, far brighter than the surrounding surface, is situated. A comparison of these with resolved clusters led Herschel to the conclusion that the nebulosity could not consist of stars, for if we regard it as such we are placed in a dilemma. Either the central body is of such enormous dimensions that it cannot be compared to true stars, since it so far exceeds its surroundings in brilliancy, or, if it is a true star, the luminous points which compose the surrounding nebulosity must be infinitely small, since even the most powerful tele-

[e] *Phil. Trans.*, 1786, p. 457. [f] *Ibid.*, 1791, p. 71.

scopes are unable to distinguish them. The supposition that the connection of the star and nebula is only apparent is untenable if we consider the large number of these objects which are known.

Herschel preferred to regard the central body as a true star, and the surrounding nebulosity as composed of a shining nebulous fluid of unknown nature, and adds, "what a novel idea, this fluid shining to us from the distant stars,—can we compare it to the Aurora Borealis, or zodiacal light, either of which would be invisible to the nearest fixed star?"

The possibility that the nebulosity might be due to the reflection of the rays of the central star by an atmosphere of enormous extent Herschel dismissed, on the ground that such reflected light would never reach our eyes.

Arago[g] took exception to this argument, giving as his reason that unless we assume an absorptive power in space, the light from a disc subtending a visible angle would reach our earth undiminished, the apparent size of the disc alone decreasing as the square of the distance.

Having once granted the existence of a self-luminous nebulous matter surrounding certain stars, it is but a short step to suppose that such matter may exist apart from any star, and Sir William suggests that such is perhaps the nature of the great nebula in Orion.

We have seen how earlier astronomers conceived that new stars which had from time to time appeared might have their origin in the condensation of a nebulous matter, and we now find Herschel writing: "If, therefore, the matter is self-luminous, it seems more fit to produce a star by its condensation than to depend upon a star for its existence." He suggests that planetary nebulæ are masses of condensed nebulous fluid, whilst those which present nuclei of different degrees of intensity exhibit the various stages of star formation.

It now became necessary to classify these various objects, and to separate star-clusters proper from true nebulæ: ac-

[g] *Annuaire du Bureau des Longitudes*, 1842.

cordingly, in 1802[h], he grouped the heavenly bodies under twelve heads, viz. :—

1. Single Stars.	7. Nebulæ.
2. Double Stars.	8. Stellar Nebulæ.
3. Treble, &c., Stars.	9. Milky Nebulosity.
4. Clustering Stars.	10. Nebulous Stars.
5. Groups of Stars.	11. Planetary Nebulæ.
6. Clusters of Stars.	12. Planetary Nebulæ with Nuclei.

Nebulæ here signify star-clusters difficult of resolvability, whilst the term "Milky Nebulosity" is reserved for the true nebulous matter.

This view of the nature of the nebulæ would receive great support from any evidence of change of form, and such evidence Herschel thought that he had obtained in the case of the great nebula in Orion.

He put forward no suggestions with regard to the nature of the nebulous matter, and even asserts that it would be presumptuous to guess at it; "for," he says, "if it should be surmised, for instance, that this luminosity is of the nature of the zodiacal light we should then be obliged to admit the existence of an effect without a cause. An idea of its phosphorical condition is not more philosophical, unless we can shew from what source of phosphorical matter such immeasurable tracts could draw their existence."

No passage in his writings would lead us to suppose that he regarded them as areas of incandescent gases.

In 1811 Herschel expounded more fully his theory of sidereal aggregation, and adduced the following arguments in its support[i].

If we examine the great nebula in Orion we notice that some parts are brighter than others. This unequal brightness can only be due to one of two causes: either there is greater condensation in the brighter parts, or greater depth. If we assume the first (for the latter would involve a number of cylindrical prolongations with their axes lying along the line of sight), the line of reasoning which was previously applied to clusters may be equally well applied to nebulous matter, and the different kinds of nebulæ may be taken to

[h] *Phil. Trans.*, 1802, p. 477. [i] *Ibid.*, 1811, p. 269.

represent the different stages of condensation; double nebulæ being formed by the attraction of two separate, but neighbouring, centres. Amongst the planetary nebulæ there are objects with all degrees of central condensation, from the evenly-illuminated disc of the planetary nebula proper to the well-defined nucleus of the nebulous star.

Observations shew, moreover, that when an elliptical nebula has an advanced nucleus, the nebulosity immediately surrounding the nucleus is reduced in brilliancy, whilst in some cases a fainter circular nebulosity, or chevelure, surrounds the nucleus.

Herschel did not regard such elliptical nebulæ as foreshortened discs, but rather as possessed of long arms, such as those of the zodiacal light; and he suggests that if the matter from the arms is always flowing in towards the central chevelure the meeting of the streams must produce a vortex motion, unless, contrary to all observation, the arms are so symmetrically placed as to be equally distributed about a line which passes through the actual centre of the nucleus. "Does it not seem," he adds, "that in this we see some natural cause which gives to a celestial body a movement of revolution in the very act of its formation?"

Here the theory of sidereal aggregation stops, and here begins the nebular hypothesis enunciated by Laplace in 1799.

Laplace, starting with the rotating spheroid of highly condensed nebulous matter, shewed how such a spheroid would throw off rings from its equatorial regions by virtue of its rotation, and the centrifugal force thereby induced. How these rings would break, and their substance would collect into lesser spheroids, revolving on their axis in virtue of the greater velocity of the outer parts of the rings from which they were formed, and revolving around the central body in the direction of their axial rotation. These planets would throw off lesser rings which would repeat the story of their parents' birth and form their satellites, so that finally there would be formed a sun such as ours, surrounded by a planetary system.

The evenly-illuminated discs of the planetary nebulæ found no readier explanation on the nebulous than on the stellar theory. If they are regarded as vast suns encased in luminous clouds, it is evident that the brightness of the cloudy covering must be far inferior to that of the solar envelope[k]. In one of his attempts to explain the appearance presented by these objects, Herschel, in an almost prophetic passage, such as is sometimes met with in the works of men whose ideas were in advance of the knowledge of the times in which they lived, suggested an explanation which approaches the true solution of the problem as nearly as was possible whilst the law that incandescent gases absorb the rays which they themselves emit was unknown.

This passage, which was quoted by Mr. Huggins[l] in 1864, runs as follows:—

"Admitting planetary nebulæ to be globular collections of nebulous matter, they could not appear equally bright if the nebulosity of which they are composed consisted only of a luminous substance perfectly penetrable to light. At least this could not happen unless a certain artificial condensation were introduced, which can have no pretension to probability in its favour. Is it not rather to be supposed that a certain high degree of condensation has brought on a sufficient consolidation to prevent the penetration of light, which by this means is reduced to a superficial planetary appearance[m]?"

An objection was soon raised to the theory of sidereal aggregation, on the ground that matter of such tenuity could not condense to form the stars, the mass of which is so great. This was answered by shewing how immense the size of these nebulæ must be, for such an object subtending an arc of 10′, if at the distance of the stars of the 7th or 8th magnitude, must have a volume a trillion times as great as that of the sun. This must represent an enormous mass of matter, and there is no difficulty in imagining it as equal in density to the sun if condensed to the same bulk[n].

Those remarkable cases in which stars are so situated in relation to nebulæ that we are irresistibly led to the con-

[k] *Phil. Trans.*, 1802, p. 477. [l] *Ibid.*, 1864.
[m] *Ibid.*, 1811, p. 315. [n] *Arago.*

clusion that a connection exists between them, did not escape notice[o]. The appearance of nebulous stars points in the same direction, as also do those objects in which a star, situated upon a ground of faint nebula, is surrounded by a chevelure of greater brightness, as if the star were drawing the matter of the nebula to itself.

Sir William considered that if in the first-mentioned cases the stars had been formed from the nebula, they must necessarily have occupied a central position; whereas the stars are usually situated at the extremities of the nebula. He accordingly suggested that the nebulosity might be attracted by a star or cluster, having come within the sphere of its influence, the cluster spreading a net, so to speak, for the drifting nebulous matter.

He had noticed that star-clusters frequently contain irresolvable regions, and since a middle condition between nebula and cluster can have no existence, for a globular nebula by its condensation can produce only a single star, he ascribed the appearance to nebulous matter thus entangled in a cluster.

We must not omit to mention that in 1802 appeared a third catalogue of 500 new nebulæ and clusters.

We have now passed in review the chief points of Sir William Herschel's work upon the nebulæ. We have seen him occupied with their distribution in the heavens, then speculating upon the clustering of stars, and later upon the aggregation of nebulous matter into stars, and we must now pass on to the work of later astronomers. We shall find, as we follow out this history, that his ideas, although rejected by the leading English exponents of the science in the following generation, are now found to have approached more nearly to the truth than those of his critics.

In 1822 Herschel died, having done much to advance the great science which was so dear to him, and his careful observations and fertile speculations have rendered the name of Herschel honoured and respected wherever astronomy has its followers.

His caution and anxiety to avoid all hasty generalization

[o] *Phil. Trans.*, 1814, p. 248.

is well illustrated by the fact that although his first observation of a true nebulous star was made in October, 1784, his paper on these objects was not published until 1791, and in connection with these very observations he wrote: "I laid down a rule not to reason upon phenomena which may present themselves, till I should be in possession of a sufficient stock of materials to guide my researches."

CHAPTER II.

The Ascendency of the Stellar Theory.

As we have said, the views of Sir William Herschel did not by any means meet with universal acceptance. Amongst the most vigorous opponents of those views in the next generation was his son, Sir John, whom we find in 1826[p] discussing some reputed changes in the aspect of the nebula in Andromeda.

Le Gentil, after stating that the light of this nebula was perfectly uniform in all parts, had added:—

"The description which Simon Marius has left us of the nebula of Andromeda scarcely accords with my observations; according to him the rays of light of which it is composed become more brilliant as one approaches the centre."

If Le Gentil's account be true the nebula must be in a state of rapid condensation, for the brightness undoubtedly increases from the circumference inwards, acquiring a sudden considerable augmentation in the centre.

In 1764 Messier, who was familiar with Le Gentil's description, wrote: "The centre appears fairly brilliant without any appearance of stars, and the light diminishes from centre to circumference."

Taking into consideration these facts, and also other passages in Le Gentil's writings, Sir John was led to the conclusion that Le Gentil did not mean by his words exactly what we understand from them, and expressed great scepticism as to any real change.

Meanwhile Mr. Dunlop had been working on the subject of nebulæ at Paramatta, New South Wales[q]. He stated that he could find scarcely any nebulæ in a high state of central condensation, very few in a state of even moderate condensation, but a considerable number were found to be slightly brighter in the central parts. Whilst regarding it as established beyond all doubt that star-clusters when situated at great distances assume a nebulous appearance,

[p] *Mem. Roy. Ast. Soc.*, 1826, ii. 494.

[q] *Phil. Trans.*, 1828, p. 113.

he considered that the question whether all nebulæ are merely star-clusters was a problem beyond the reach of the human intellect, but concludes by saying that, since many nebulæ had not been resolved, "Shining matter may exist in a state different from the starry."

Sir John Herschel, in the notes to his celebrated Catalogue of 2,306 nebulæ and clusters [r], suggested that the nebulous appearance of stars may sometimes be caused by their shining through a very attenuated medium in the higher regions of our atmosphere, perhaps that of the Aurora. He adds that he has often observed stars to put on a nebulous appearance for a time, but he is far from contending that no stars are really nebulous. He also draws attention to the frequent proximity of small stars to nebulæ, and suggests that they may perhaps be of the nature of satellites. After remarking that elliptical nebulæ might be regarded as oblate spheroids of every degree of flatness, he adds :—

"It would be incorrect to draw from this any inference as to the identity of the forces which maintain them in this form, and those which determine the oblate spheroidal form of a revolving fluid mass under the dominion of the law of gravitation, and subject to compression by the superincumbent matter.

"If nebulæ be nothing but star-clusters no pressure can be propagated through them, and their form must be maintained by totally different means. No general rotation of such a system can be supposed. It must rather be conceived as a quiescent form, comprising within its limits an indefinite number of individual constituents. It may be shewn how a quiescent spherical form may subsist as a bounding outline to an immense number of equal stars uniformly distributed through its extent, each of which attracts all the others with a force inversely as the square of the distance, and the united attractions of which compose an internal force acting upon each star, with an intensity directly proportional to the distance from the centre of the sphere. In such a state of things each star might describe an ellipse

[r] *Phil. Trans.*, 1833, p. 359.

in any plane, and in any direction in that plane, about a common centre, without possibility of collision, but the sphere regarded as a whole would have no rotation about its axis."

Herschel spent the next five years at the Cape of Good Hope, where he was engaged "in raising to his father the most splendid monument that son ever erected,—the completed survey of the vault of heaven [s]."

In his volume of "Astronomical Observations made at the Cape" he speaks of the reputed changes in the nebula in Orion, and gives it as his opinion that they have chiefly arisen from faults in drawing, and differences of power in the telescopes employed, but quotes several facts as demanding attention, as evidences of actual change.

We have seen that his leaning was always towards the stellar theory, and in the work before us he expresses inability to conceive of the nature of a nebulous fluid capable of radiating light of the intensity of that emitted by these objects. If again we imagine them to be clouds suspended in a medium, and prevented from rushing together and condensing to a point by the resistence offered by that medium, is not such a medium quite hypothetical?

Here also we have the earliest accurate observations of the Magellanic clouds, or nuberculæ, two large nebulous spots only visible from the southern hemisphere, the larger of which occupies an area of 42, the smaller of 10, square degrees.

In these clouds Herschel discovered, in addition to single stars scattered throughout, a number of clusters and irresolvable nebulæ, which were found to stand to each other in the following numerical relation:—

In the nubercula major, 583 stars, 291 nebulæ, 46 clusters.

In the nubercula minor, 200 stars, 37 nebulæ, 7 clusters.

These luminous areas, which have no apparent connection with each other, nor with the milky way, have been long known, and two notices of them even earlier than that of Magellan in 1521 have been discovered. They were de-

[s] *Dr. Whewell.*

scribed by Andrea Corsali, a Florentine, in his "Voyage to Cochin" (1515), and mentioned by Petrus Martyr de Anghiera, secretary to Ferdinand of Arragon, in his work, *De rebus Oceanis et orbe Novo.*

Meanwhile, an American astronomer, E. P. Mason [t], who unfortunately died young, had been confirming the observations of the elder Herschel in almost every particular, and gave accurate drawings and descriptions of the objects which he observed, in the hope that they might serve as guides to future investigators.

In the *Annuaire du Bureau des Longitudes* for 1842, the illustrious French astronomer, Arago, gave an account of Sir William Herschel's life and works. As might be expected, the nebulæ are here discussed at length. Speaking of planetary nebulæ, after mentioning Herschel's views, Arago suggests that all these suppositions might be avoided if we regard these objects as nebulous stars, situated at such enormous distances from the earth that the brightness of the central star does not exceed that of the surrounding nebulosity. This explanation is based upon the well-known optical principle, that whereas the light from a point diminishes as the square of the distance, that from an illuminated surface is equally bright at all distances, the only decrease being in the angle subtended. The light of the surrounding nebulosity may either be intrinsic or reflected from the central sun.

Sir John Herschel [u] objected to this explanation, on the ground that if we suppose the envelope to reflect one-half of the light of the star, and to distribute it equally in all directions, the extremely small fraction of this light which would reach our eye could not exceed in brilliancy the light which still comes from the central sun by direct radiation. We assume, however, that this direct radiation is insufficient to affect the eye, even when concentrated to a single point; how then can the light from the surrounding nebulosity, which is distributed over a very considerable surface, many million times exceeding that of the central sun?

[t] *American Phil. Soc. Trans.*, 1840 (Philadelphia), p. 165.

[u] *Outlines of Astronomy* (1849), p. 646.

To this Arago[x] replied, that he saw no reason why reflected light should be extinguished in its passage through space any more than direct light; and he shewed that whereas at the distances 3, 4, 10, 100 respectively the light of the central star would be successively reduced to $\frac{1}{9}$, $\frac{1}{16}$, $\frac{1}{100}$, $\frac{1}{10000}$ of its original brilliancy, the apparent area of the nebulosity would become 3, 4, 10, 100 times less, the amount of light received being the same.

Meanwhile there was in process of construction at Parsonstown Lord Rosse's first great telescope, the speculum of which had a diameter of three feet[y].

On its completion it was soon directed to the nebulæ, which have always held a prominent position amongst telescopic test-objects. As these early observations were made chiefly with a view to testing the capabilities of the instrument no micrometrical measurements were made.

Under this enormous optical power many nebulæ assumed appearances very different from those which they presented to Herschel. The well-known Dumb-bell Nebula lost much of its apparent regularity of form, and several planetary nebulæ assumed an annular appearance.

Sir John Herschel had included in the category of resolvable nebulæ not only those objects which his telescope was able distinctly to resolve into stars, but also certain others which exhibited appearances which he took to be indications of the possibility of resolution by yet higher powers; and the observations of Lord Rosse yielded strong confirmation of the accuracy of Herschel's judgment in this matter, so much so that he considered himself justified in concluding that these same signs might safely be trusted as signs of resolvability beyond the reach even of his own instrument.

At the same time he does not pretend to say that absence of any signs of resolvability can be taken as in any way conclusive evidence that the object is not a cluster of stars, for in the case of many objects, which with smaller telescopes, had shewn no such signs, they were well marked on in-

[x] *Astron. Populaire*, bk. xi. chap. iv.

[y] *Phil. Trans.*, 1844, p. 321.

creasing the optical power, whilst a still further increase has shewn them clearly resolved.

It would have been natural to conclude from the observation that increase of optical power always tended to increase the number of resolved, or apparently resolvable, nebulæ at the expense of the irresolvable, that resolvability was merely a question of optical power, and that all nebulæ would eventually yield to yet more powerful telescopes. Lord Rosse was not, however, prepared to go so far as this, and although speaking of the inference as obvious, he did not regard it as a safe one.

Sir John Herschel appears to have had no such hesitation. Any doubts which he may have had formerly of the truth of the stellar theory were dispelled by Lord Rosse's observations, and in 1845, in his address as President of the British Association, when speaking of planetary nebulæ, he said[z]:—

"I should have little hesitation in admitting all such nebulæ to be in fact congeries of stars."

In his "Outlines of Astronomy" (1849), also, we have the stellar theory warmly advocated, and we find him saying, "Although nebulæ do exist, which even in Lord Rosse's powerful telescope appear as nebulæ without any sign of resolvability, it may very reasonably be doubted whether there be any essential physical distinction between nebulæ and clusters of stars." He did not, however, shut his eyes to the objections to this view, and he again states the observation, upon which he had dwelt at considerable length in his presidential address at Cambridge, that elliptical nebulæ are in all cases more difficult to resolve than circular ones. He also remarks upon the bluish tint usually exhibited by planetary nebulæ, a tint which is never met with in ordinary stars, except in those cases where one component of a double star is red, when the other appears blue by contrast.

Sir John asserts, moreover, that the appearance of these objects cannot be reconciled with the view that they are globular clusters of stars, for in that case we should inevitably observe a central condensation, and suggests that they may perhaps be hollow shells of stars, or flat discs,

[z] *British Association Reports*, 1845 (Cambridge), p. xxxvii.

presented to us by a remarkable chance in a plane perpendicular to the visual ray.

In 1848 Mr. G. P. Bond[a], when examining the great nebula in Andromeda with the great Harvard refractor at Cambridge, Mass., discovered two perfectly straight dark bands which stretched across the whole surface of the nebula. These bands had not been noticed by any previous observer, but one of them appears to have been previously regarded as the limit of the nebula towards the side on which it occurs.

Meanwhile Lord Rosse was constructing a telescope far exceeding his previous instrument in power. The speculum had a diameter of 6 feet, and the focal length was 53 feet[b].

Examined with this gigantic instrument the nebula 51 Messier, in which Sir John Herschel had seen a system consisting of a central globe surrounded by a vast ring, split for some distance, completely altered its appearance. It now presented the aspect of a spiral, attended by a companion which also appeared to be associated with spiral streamers.

That such a system could exist without internal movement appeared to Lord Rosse, as it must appear to all, in the highest degree improbable.

Measurements, although they must necessarily be most difficult, would possess the greatest interest, as tending to bring to light any movement in this wonderful system.

This appearance, which was first noticed in the spring of 1845, had been observed by many visitors, and the general resemblance to the sketch at once recognized. Thirteen other nebulæ shewed indications of similar forms.

The spiral appendages did not appear to Lord Rosse incompatible with a starry nature, since in many authenticated clusters there is a tendency to an arrangement in curved branches.

Planetary nebulæ, when observed with this instrument, appeared in some cases annular, and in others exhibited a still more remarkable appearance. An object described

[a] *Memoirs of the American Academy*, 1848, vol. iii. New Series, p. 75.

[b] *Phil. Trans.*, 1850, p. 499.

by Sir John Herschel as a nebulous star appeared as a star surrounded by a nebulous ring shewing no signs of resolvability, whilst some nebulæ presented a knotted appearance.

Speaking of these observations Lord Rosse says,—

"Much as the discovery of these strange forms may be calculated to excite our curiosity, and awaken an intense desire to learn something of the laws which give order to these wonderful systems, as yet I think we have no fair ground for plausible conjecture, and as observations have accumulated the subject has become, to my mind at least, more mysterious, and more inapproachable; there has been therefore little temptation to indulge in speculation, and consequently there can have been but little danger of bias in seeking the facts."

The modifications which Lord Rosse's observations have introduced in our conception of the forms of the nebulæ must lead us to be very cautious in forming any theories to account for those forms. It is obvious that any speculations based upon the apparently circular disc of a planetary nebula become valueless when applied to the fantastic shapes which they assume in Lord Rosse's instrument, and we cannot be sure that still further increase of optical power might not introduce still further complications.

The views of Sir John Herschel and his supporters did not by any means meet with universal assent. The English astronomers, however, seem as a rule to have adopted the stellar theory, and it is this view which we find expounded in the text-books of that period, many passages from which might be quoted to illustrate this point. A notable exception is to be found in Admiral Smyth's "Celestial Cycle."

These views were also opposed by some leading continental astronomers. Arago, in his *Astronomie Populaire*, advances opinions identical with those which he had advocated in the *Annuaire du Bureau des Longitudes*. Humboldt, in the *Kosmos* (1852), says that it is very unlikely that all nebulæ will ever be resolved, since increase of optical power adds to the number of known unresolved nebulæ as many objects as it removes into the category of star-clusters.

Dr. Whewell, in his work "The Plurality of Worlds [c]," attacked the theory vigorously, his chief argument being deduced from Sir John Herschel's observations of the Magellanic Clouds [d]. We have seen that these objects are composed of stars, clusters, and nebulæ, and Dr. Whewell asks how nebulæ, if they are merely very distant clusters, can here exist in association with isolated stars and undoubted clusters? The only possible manner of reconciling these facts is to suppose that the two nuberculæ are immensely long cylinders, both so placed by a marvellous coincidence that their major axes are in the line of light. If, on the other hand, we regard them as approximately spherical in form, the diameter of the larger cloud can only be about a tenth part of the distance of its centre from the earth, a distance obviously quite insufficient to produce the observed effect.

Dr. Whewell was further bold enough to assert that the resolution of nebulæ into bright points is not an adequate proof that they are composed of true stars.

It is obvious that this question was one of great interest to the supporters of the nebular hypothesis of Laplace, for if we do not allow the existence in the heavens of a nebulous matter, their hypothesis has no *locus standi*, for no one would attach any credit to a theory which endeavours to account for the development of the solar and other systems from a certain kind of matter, when we have no evidence whatever that such matter exists, or ever has existed, under the conditions required by that theory.

We are accordingly not surprised to find the adherents of Laplace amongst the most vigorous opponents of the stellar theory. Conspicuous amongst these was Mr. Herbert Spencer, who, in his essay upon the Nebular Hypothesis [e], added another argument to those of Dr. Whewell. This was based upon Sir W. Herschel's observation that nebulæ occur in those portions of the heavens which are poor in stars, and his habit of taking a thin field as a warning of the proximity of nebulæ. "How," says Mr. Spencer, "can we conceive that in a thousand cases the line of sight

[c] 1854. [d] p. 225. [e] *Westminster Review*, 1858.

upon which these remote objects are situated passes through a region poor in stars, unless we assume some connection between the stars and nebulæ? If we grant this, we must suppose them to be part of our sidereal system, and not so very remote." He ends by saying, "What, then, is the conclusion that remains? This only: that the nebulæ are not further off from us than parts of our own starry system, of which they must be considered members, and that when they are resolved into discrete masses, these masses cannot be considered as stars in anything like the ordinary sense of the word."

It is no doubt most difficult, if not impossible, for us, with our fuller knowledge, to enter into the spirit of this controversy, for how shall we dismiss from our minds the impressions produced by more recent discoveries, and carry ourselves back into a phase of thought which is now a thing of the past? We cannot but imagine that the theory so warmly advocated by so careful an observer as Sir John Herschel must have appeared in the then state of knowledge the most capable of explaining the known facts, but it is at the same time remarkable that the apparent objections to that view seem to have so little modified his opinions.

As bearing on the details of structure of nebulæ, we must not omit to mention an observation of Mr. Lassell's made at Malta in 1862, and announced in a letter to Mr. De La Rue[f]. When observing one of the planetary nebulæ he found that with a low power it appeared to resemble the planet Saturn with its ring system seen edgewise, but with a higher power he observed within the nebula a brilliant elliptical ring, well defined, and having apparently no connection with the surrounding nebulosity, which had a gauzelike appearance, and did not impair the definition of the ring, the thickness of which, unlike that of Saturn, was equal in every part. It follows from this that if the ring is really circular, and is here seen foreshortened, its cross-section must be also circular.

We must now return to the preceding year, 1861, in

[f] *Proc. Roy. Soc.*, 1862, xii. p. 108.

which Lord Rosse announced [g] that some supposed changes had been brought to light during his observations, and regretted that no micrometric observations had been made.

The most remarkable evidence of change was in the case of a double nebula, H 1905. In Herschel's drawing of this object the two components were represented with their axes in a line.

On April 11, 1850, Mr. Johnston Stoney remarked that the two nebulæ were not in a line, but their axes were parallel.

On April 17, 1855, Mr. Mitchell remarked that the two nebulæ were not in a line; and in 1861 they were neither in a line, nor were their axes parallel, but inclined at an angle of 16°.

Now it is obvious that the satisfactory establishment of changes of such magnitude amongst the nebulæ would afford a strong argument against their starry nature; and it is a remarkable fact that a series of observations of such changes about this time served to shew the insufficiency of the stellar theory, and prepared astronomers in some measure for Mr. Huggins' great discovery in 1864.

On Oct. 19, 1855, M. Chacornac, working with Leverrier at Paris, had discovered a nebula in the constellation Taurus, which he thought could hardly have been overlooked by former astronomers.

On Oct. 19, 1859, M. Tempel discovered a nebula, also in Taurus, which he at first mistook for a telescopic comet, but the true nature of which was soon revealed by its immobility.

On Dec. 13, 1860, MM. Tempel and Papé again found this nebula, though with some difficulty, and M. Amvers suggested that it had been missed by former observers on account of its proximity of Meropé, one of the Pleiades.

In 1860 [h] Mr. Pogson, Director of the Hartwell Observatory, published an account of some remarkable changes observed in the nebula 80 Messier, which is situated near the variable stars R and S Scorpii. This object had always presented the appearance of a well-defined nebula, but on

[g] *Phil. Trans.*, 1861, p. 681. [h] *Ast. Soc. Monthly Notices*, 1861, p. 32.

May 26, 1860, Mr. Pogson observed a star of the seventh or eighth magnitude in the position which it had previously occupied. On May 9, the last night on which R Scorpii was visible, he is positive that the nebula was as usual, and had nothing stellar in its appearance, the same instrument being employed and the same power.

On June 10, with a lower power, the stellar appearance had nearly vanished, but the nebula was still more than usually brilliant, and shewed a marked central condensation.

Pressure of anxious business banished this observation from Mr. Pogson's mind, and he neglected to publish it. He mentioned it, however, to Mr. Hind and Dr. Lee. He was reminded of it by the arrival of No. 1267 of the *Astronomische Nachrichten,* which announced that M. Amvers and Professor Luther had perceived the same change on May 21.

Mr. Pogson attributed this phenomenon to the appearance of a new star which for a time eclipses the light of the nebula, and he remarks that it is most extraordinary that a third variable star should exist in such close proximity to R and S Scorpii.

In 1862, Professor D'Arrest of Copenhagen announced that a nebula in Taurus, which had been discovered at the Regent's Park Observatory on Oct. 11, 1852, had totally vanished from the heavens[1]. Concerning this observation Mr. Hind wrote, in a letter to the "Times:"—"That one of these objects which the giant telescopes of the present day have taught us to regard as assemblages of stars, in myriads, at immense distances from our earth should suddenly fade away, so as to be quite invisible in powerful instruments, must, I think, have been deemed a very improbable occurrence, even by those who are acquainted with the care and experience of the observer by whom the statement was made. Within the last few days, however, M. Leverrier has obtained so strong a confirmation of its accuracy, that there is no longer room for supposing it to have originated in one of the errors of observation, which every practical

[1] *See Letter of Mr. Hind, in "Times," Feb.* 4, 1862.

astronomer knows will creep into his work in spite of all precautions." Father Secchi also failed to see any trace of the nebula.

Matters were further complicated by the fact that a star of the tenth magnitude, situated very near to the nebula, which had frequently been observed by D'Arrest and Hind, had dwindled to the twelfth. From the fact that M. Chacornac had observed the nebula in 1854, and did not remark it whilst going over the same region in 1858, we may safely infer that the disappearance took place between those dates.

To attempt to reconcile these observations with the stellar theory, was almost a hopeless task. Mr. Hind suggested that a dense body interposed between the earth and the nebula might account for the observed phenomena, but thinks that it depends rather on some connection between the star and the nebula, upon which alterations in the visibility of the latter might depend. If only we could imagine that the nebula shone by light reflected from the star, it is evident that the waning of the latter would be attended by the waning, or even extinction, of the former.

The association of variable stars with nebulæ is not uncommon, several being contained within the area of the great nebula in Orion.

Lastly, Mr. Abbot noticed, in 1863, that η Argus, which, when examined by Sir John Herschel in 1838, was situated in the most brilliant part of the nebula, which derives its name from it, and was of the first magnitude, was then out of the nebula, and only of the fifth magnitude. In 1860, Mr. Powell had called attention to the fading of this nebula and to its alteration in form.

This remarkable series of observations presents a problem to the solution of which it must be confessed we have not made much approach. They were, however, obviously irreconcilable with the stellar theory, for it is inconceivable that a mass composed of myriads of individual stars should quickly lose its lustre, unless indeed we assume a diminished transparency of the intervening space.

In the year 1864 Sir John Herschel issued his last contribution to nebular astronomy, his splendid catalogue of 5,079 nebulæ and clusters, which formed Part I. of the Philosophical Transactions for 1864. The *Astronomische Nachrichten* of the same year contained an elaborate series of observations of the circumpolar nebulæ by Rümker.

CHAPTER III.

Mr. Huggins' Work.

All that the telescope could do had now been done. Increase of optical power, although it had proved most valuable in the study of their form, had failed utterly to solve the problem of the constitution of the nebulæ. This solution was left for the spectroscope, an instrument of more varied powers, which has rendered possible a new science, that of Cosmical Chemistry, by enabling the astronomer to read in the light of the sun and stars their chemical and physical constitution. How great must be the interest of such a study will be evident if we consider that chemistry, as hitherto studied, is but a branch of this far wider science. In the study of Terrestrial Chemistry our conceptions are profoundly modified by our surroundings. The range of temperature which we can command is limited. In the sun and stars, however, which may be regarded as furnaces of far greater power than any terrestrial source of heat, Mr. Norman Lockyer thinks that he is able to detect evidences of the dissociation of our elements.

In 1864 the light of certain fixed stars had been already submitted to prismatic analysis by Huggins and Miller, who found that the majority of them yield spectra in every respect analogous to that of the sun.

Encouraged by the results so obtained, and in spite of the extreme faintness of the light yielded by the nebulæ, Mr. Huggins determined to attempt to gain some insight into the nature of these objects by similar means. Accordingly, on the evening of August 29, 1864, he directed his telescope, with the spectroscope attached, to a nebula [k].

The object selected for observation was a small, but bright, planetary nebula, which shewed a small nucleus, and a gradual increase of brightness towards the centre.

If the nebulæ are star-clusters the spectrum so obtained

[k] *Phil. Trans.*, 1864, p. 437.

should be the same as that from a single star, namely, a continuous spectrum crossed by dark lines.

The result was, however, very different. Indeed the appearance presented was so unexpected that Mr. Huggins was led to suspect some derangement of his instrument, for in place of a spectrum a single short line of light was visible, perpendicular to the direction of dispersion. Further observations shewed conclusively that the light of this nebula, unlike that of any extra terrestrial source of light which had been previously subjected to spectrum analysis, could not form a continuous spectrum. Employing a narrower slit he was able to detect a second much fainter line exceeding the first in refrangibility, and separated from it by an interval only illuminated by traces of an extremely faint continuous spectrum, and beyond this again an even fainter third line about three times as far from the first. The faint continuous spectrum gave indications of being crossed by dark lines.

Mr. Huggins concluded from this that the nebulæ are masses of incandescent gas, for such a spectrum can only proceed from a gaseous source. It is indeed conceivable, as he shewed, that a cluster of suns surrounded by vast atmospheres might present photo-surfaces fulfilling the required conditions, but he considered that the observed phenomena precluded the adoption of such an explanation. This view has since been advocated by Mr. Stone, the Radcliffe Observer at Oxford[1].

The discovery that the light which we receive from the planetary nebulæ emanates from areas of incandescent gases disposed at once of the difficulty which had been experienced by all observers who preceded Mr. Huggins in reconciling the probably spherical form with the absence of central condensation, for this appearance follows as a necessary consequence from the physical law that incandescent gases absorb the rays which they themselves emit. The outer layers quench all the light from the central regions, so that the rays which reach the eye come entirely from the superficial layer.

[1] *Then Astronomer Royal at the Cape.*

Mr. Huggins soon extended his observations to other nebulæ, and found that many of them yielded the same three lines with or without the faint continuous spectrum, which he attributed to the light from the nucleus. Some, such as 4964 H, which, with a power of 600 appeared distinctly annular, gave a fourth line, about as far from No. 3 as No. 3 is from the brightest line.

The great nebula in Andromeda gave a continuous spectrum from D to F.

This nebula and some others yield continuous spectra, the mottled appearance of which suggests that they are not star-clusters. In no case was any line observed less refrangible than the brightest line.

It became a question of great interest, in connection with these researches, to ascertain how far the results obtained with the telescope and spectroscope agreed together, that is to say, whether those nebulæ which yield gaseous spectra are just those which the telescope has failed to resolve into stars. Accordingly Mr. Huggins asked Lord Oxmantown[m] to direct his telescope to those nebulæ which had been submitted to spectrum analysis. And the results of this examination are contained in the following table, taken from one of Mr. Huggins' papers[n] :—

Telescopic appearance.	*Continuous spectrum.*	*Gaseous spectrum.*
Clusters	10	0
Resolved ; or resolved ?	5	0
Resolvable ; or resolvable ?	10	6
Blue or green no resolvability	0	4
No resolvability seen	6	5

This table shews that in most cases starry points, when detected, may be regarded as true stars, but that the apparent indications of resolvability cannot be relied on. Mr. Huggins adds :—

"I have Lord Rosse's permission to state that the matter of the great nebula in Orion, which the prism shews to be gaseous, has not been resolved by his telescope. In some parts of the nebula he observed a large number of exceed-

[m] *Now Lord Rosse.*

[n] *Phil. Trans.*, 1866, p. 381.

ingly minute red stars; these red stars, however, though apparently connected with the irresolvable blue material of the nebula, seem to be distant from it. The light of these stars is doubtless too feeble to form a visible spectrum[o]."

The fact having been established that the spectra of all nebulæ which give indications of a gaseous constitution contain the same lines, the comparison of these lines with those of the terrestrial elements became a matter of great interest. In the case of the two brighter lines this comparison has been attended with great difficulty.

Whilst the two faintest lines agree absolutely in position with the F and H lines of hydrogen, Mr. Huggins has failed to find any coincidence for the second line, which is slightly less refrangible than the strong Barium line, 2075 in Huggins' scale, and slightly more refrangible than the oxygen line 2060. A strong iron line also approaches it very nearly lying between 4956 and 4957 on Ångström's, scale, on which the nebula line occupies the position 4957[p].

The brightest line corresponds in position with the most conspicuous of the air lines, which is due to nitrogen, and of the thirty elements with which it was compared no other had a bright line near to that of the nebula. A careful comparison with a nitrogen spectrum, obtained by passing an electric spark through pure nitrogen[q], contained in a sealed tube at slightly reduced pressure, revealed a coincidence quite as perfect as that previously observed. This line is, however, double in the nitrogen spectrum, whereas a most careful scrutiny did not enable Mr. Huggins to divide the line in the nebula[r].

This difference loses much of its importance from the fact that the spectrum from a spark passed in air between platinum electrodes before the object-glass of the telescope shews only a single line, which is slightly broader than that of the nebula. Plücker has also shewn that at a very high temperature the two components amalgamate to form a single line.

[o] *May not the colour of these stars be due to the absorption of their blue rays in their passage through the nebulous matter?* [p] *Proc. Roy. Soc.*, 1872, xx. p. 379. [q] *Phil. Trans.*, 1868. [r] *Proc. Roy. Soc.*, 1866.

Mr. Huggins regards Secchi's observation, in which he saw the line double in a nebula, as an optical delusion, due to his employment of a cylindrical lens instead of a slit in a direct vision-spectroscope.

The fact that this line is the last to be extinguished when a wedge of neutral-tint glass is caused to pass gradually before the nitrogen spectrum, raises the question whether, assuming that it is due to nitrogen, the other lines are extinguished by an absorptive power in space, such as has been assumed on altogether different grounds by Cheseaux, Olbers, and Struve; or whether these lines represent the entire light of the nebula. In the latter case the constituents must be in a simpler condition than terrestrial elements, and such a supposition would agree with Lockyer's theory.

When observing the spectrum of the nebula in Orion, a few years later[s], Mr. Huggins employed a spectroscope with two compound prisms, and a large telescope provided by the Royal Society. With a narrow slit the first line was seen to be very narrow and well defined at both edges, and certainly not double. It apparently coincided with the middle of the less refrangible nitrogen line which was nebulous and broader.

All attempts to obtain luminous nitrogen in such a condition as to present the same characters as the line of the nebula failed. Under reduced pressure, however (·1 to ·55 in.), there is a condition of the discharge in which the double line alone is conspicuous, all the others being extremely faint. It is at the same time very difficult to resolve the line into its components, since it is narrower than when a denser gas is employed, and might easily be mistaken for a single line.

Similar results have been recently obtained by M. Fievez[t], who projected upon the slit of a spectroscope, by means of a lens, a real image of the light from the bright portion of a Plücker's tube containing hydrogen, and altered the intensity by diminishing the aperture of the lens, or by

[s] *Proc. Roy. Soc.*, 1872, xx. 379.

[t] *An. Chem. Phys.*, 5, vol. xx. p. 179; *Chem. Soc. Journ.* ccxxx. 69.

placing a diaphragm in the path of the light between the tube and the lens. When the light was diminished by these means he found that the H line was the first to disappear, then followed the C line, leaving the F line only. In the case of nitrogen also the line corresponding to the nebula line was the last to disappear, and the first to reappear when the slit of the spectroscope was widened, a fact which shewed that the disappearance was due to faintness of the light.

Taking all things into consideration, Mr. Huggins is inclined to regard this line as due to nitrogen.

Capt. J. Herschel[u], in an account of his observations of some southern nebulæ, stated that he was inclined to think that the position of the bright line is not constant in all nebulæ.

Mr. Huggins found that in certain stars some of the dark lines were slightly displaced, so as not to agree exactly with the corresponding terrestrial lines. This could only be due to a movement of the stars in space; for if we are journeying towards the source of the waves of light, or if that source is approaching us, it is obvious that the number of waves which we shall encounter in a given period of time will be greater than if we remained still; and, on the other hand, if we are receding from the source of light, the waves which will reach us will be fewer. As the refrangibility of light depends upon the length and frequency of the waves, the effect will be in the first case to raise the refrangibility, in the second to lower it. This law is well illustrated in the case of sound by the alteration of pitch of the whistle of an advancing or receding locomotive.

In the case of Sirius the observed displacement points to a recession of the star from the earth at a velocity of from 18 to 22 miles per second, and Lockyer has been able in the same manner to measure the velocity of the solar gas-streams.

This principle Mr. Huggins determined to apply to the nebulæ.

The smallest amount of displacement which his instrument would have enabled him to detect would correspond

[u] *Proc. Roy. Soc.*, 1868, xvi. pp. 417, 451; xvii. 303.

to a wave-length of ·0462 of a millionth of a millimetre, corresponding to ·02 of a division of the head of the micrometer screw of his instrument.

The object selected for examination was the great nebula in Orion[x], from which the earth was then moving with half its orbital velocity, and taking the velocity of light as 185,000 miles per second, and the wave-length of the nitrogen line as $\frac{500}{8000000}$ of a millimetre, the effect of the earth's movement would be to lower its refrangibility by $\frac{\cdot 023}{1000000}$, which would correspond to a movement of the screw-head of ·01 of a division, a difference which could not be detected.

No displacement could be observed; Mr. Huggins therefore concluded that if the line is really due to nitrogen, the nebula is not receding from the earth with a greater velocity than ten miles, nor approaching at a greater velocity than thirty miles per second. Ten miles being subtracted in the first case and added in the second, as compensation for the earth's movement.

At a later date, 1872, Mr. Huggins calculated that if the line is due to nitrogen and represents the united lustre of the two components of the double line, we should have evidence that the nebula is moving from the earth; for the amount of displacement of the line of the nebula from the centre of the double line of nitrogen would correspond to a velocity of 55 miles per second. From this 14·9 miles must be subtracted for the earth's movement from the nebula, and a further reduction must be made for the movement of the solar system as a whole.

In a later series of observations[y], undertaken in the hope of detecting a motion of rotation in the large nebulous globes by the displacement of the line in different directions at the two limbs of the disc, a line was employed as a standard of comparison, which appears well defined when a lead spectrum is obtained under certain conditions of the spark, and which coincides so nearly with the nitrogen line as to serve as a satisfactory standard of comparison. These observations also give negative results.

We have already noticed the different effect of distance

[x] *Brit. Assoc. Reports*, 1873, p. 31.

[y] *Phil. Trans.*, 1866, p. 381.

upon light from a point and that from a surface subtending a sensible angle, and it is obvious that in the former case the rapid decrease in the amount of light renders photometric measurements worthless. This is not the case, however, with light from a surface, unless we assume an absorptive power in space.

As the nebulæ come under the latter category, Mr. Huggins determined to compare their light with that from a terrestrial source[z].

He employed a photometer which consisted of two wedges of neutral-tint glass, which could be made to overlap to any required extent by turning a micrometer screw. The nebula being observed through the overlapping edges, the wedges were caused to overlap still further, until the thickness of neutral-tint glass interposed was just sufficient to eclipse its light.

The standard of light employed was a sperm candle (six to the pound), which was found by a series of experiments to burn at a sufficiently constant rate.

This candle, having its light diminished by a screen of neutral-tint glass, which reduced it to $\frac{1}{377}$ of its original power, was placed upon a neighbouring roof at a distance of 440 yards from the telescope.

A careful comparison of the light from this source with that of several gaseous nebulæ gave the following results.

Lustre of	Dumb Bell nebula	1 line	$\frac{1}{52}$	of that of screened candle.	
"	Nebula in Lyra	1 line	$\frac{1}{16}$	"	"
"	H 4628	3 lines	$\frac{1}{4}$	"	"

Or in terms of the unscreened candle.

$$\text{H } 4628 = \frac{1}{1508}$$
$$\text{Lyra} = \frac{1}{6032}$$
$$\text{Dumb Bell} = \frac{1}{19604}$$

[z] *Phil. Trans.*, 1868, p. 529.

CHAPTER IV.

CONCLUSION.

WHILE Mr. Huggins was engaged in his researches other astronomers were not idle.

In 1868 the present Lord Rosse published an elaborate account of the Great Nebula in the sword-handle of Orion[a]. This, which is the largest nebula in the heavens, has always received much attention from astronomers; and it will be well to glance back at the earlier work upon the subject.

It was discovered, as has been mentioned, by Huyghens in 1656, and his drawing of the nebula is the earliest which we possess.

Sir William Herschel frequently directed his attention to this object, and observations made at various times led him to the conclusion that there were evidences of change of form, and in support of this he gives some extracts from his observation-book, which run as follows:—

"1774. The shape is not like that which Dr. Smith has delineated in his 'Optics,' though somewhat resembling it. From this we may infer that there are undoubted changes among the regions of the fixed stars, and perhaps from a careful observation of this lucid spot something may be concluded concerning the nature of it."

In January, 1783, he detected changes since 1780, and in the following September a further change appeared to have taken place since January.

Twenty-three years later, on March 13, 1811, he found that with a telescope of similar power to that which he had used in his observations twenty-three years before, the arrangement of the nebulosity presented considerable differences.

The difficulty in mapping accurately an object of so undefined a shape as a nebula, must render us cautious in drawing any conclusions from such evidences, and we are not surprised

[a] *Lord Oxmantown, Phil. Trans.*, 1868, p. 57.

to find Sir John Herschel expressing considerable doubt as to the indications of change. He himself published drawings in 1825 and 1837 [b]. The next map of importance was that of Bond [c].

In 1863 M. Liapunow [d] published an elaborate description and catalogue of the stars distributed over the area of the nebula, and an appendix by Otto Struve contains the following words:—

"My observation-record contains, without doubt, some very strong indications of change in the state of the nebula."

These evidences he found, however, to be few, and are accompanied by so many records of doubtful changes that he adds, "The deceptions attending observations of this nature are so numerous, that one cannot be too guarded as to what one advances as established facts." Other drawings by Lassell and Hunter were published in 1854 and 1863.

Lord Rosse's observations above mentioned were most elaborate. He found that on comparing the above-mentioned drawings great discrepancies appeared in every part.

We have seen that this nebula is one of those which yield a spectrum of bright lines, and although it appeared to give indications of resolvability its resolution has never been announced. Mr. Lassell had compared the whole nebula to large masses of cotton-wool, pulled out at the edges so as to appear filmy, whilst Sir John Herschel used the simile of a curdled liquid. Mr. G. P. Bond, jun., had noticed a spiral arrangement having the trapezium as its centre [e].

Lord Rosse was only able to detect three bright lines accompanied by a faint continuous spectrum; as is usually the case, the least refrangible was the brightest, the middle line appeared to be the faintest [f].

Secchi [g], after remarking that the same lines which Mr. Huggins had detected in planetary nebulæ occurred in the spectrum of this nebula, adds: "Only here in this case the

[b] *Observations made at the Cape.* [c] 1848. [d] *Memoirs of the Academy of St. Petersburgh*, 1863, Pt. II. p. 1. [e] *Monthly Notices R.A.S.*, 1861, p. 203.

[f] *Proc. Roy. Soc.*, 1868. *Capt. Herschel was able to detect the fourth line in the spectrum of this nebula.* [g] *Comptes Rendus*, ix. 543.

most distant line is stronger, whereas in those nebulæ it is the feeblest." It is quite possible that some such variations in the relative brightness of the lines in different nebulæ may exist, and Mr. Huggins quotes a passage in which D'Arrest, speaking of the nebula 37 H iv., lends support to this view [h].

Le Sueur, working with a spectroscope attached to the great Melbourne telescope, was able to detect nebulosity within the central trapezium of stars [i].

Mr. Stone has advocated the view that the nebulæ may be regarded as distant star-clusters, surrounded by atmospheres of enormous extent, composed of incandescent gases. In 1877 he communicated to the Royal Society [j] a short note "On the appearance of bright lines in the Spectra of Irresolvable Clusters." After recalling the fact that previous to Mr. Huggins' discovery all nebulæ were regarded as star-clusters, he suggests that a view which had become impressed upon the minds of our greatest observing astronomers should not be lightly thrown aside. He adds that the observations of Huggins appear to him to prove rather than to disprove the stellar theory.

The arguments upon which he based his opinion were as follows :—

The sun is surrounded by an incandescent gaseous envelope, and there is every reason to believe that the same may be said of all stars. We can imagine that in a compact cluster these envelopes might flow together, so that the whole cluster would be enveloped in a continuous covering of incandescent gases. In the case of such a cluster, situated at no very great distance from us, the light from the component stars would eclipse that from the gaseous envelope, whereas at enormous distances, in accordance with the often-quoted law, the light from the starry points would disappear, and leave that from the envelope only. As the bright lines would not appear till the light from the envelope approached in brilliancy that from the stars,

[h] *Astronomische Nachrichten*, No. 1886 (1872).   [i] *Proc. Roy. Soc.*, 1870, xviii. 242.   [j] *Ibid.*, 1877, March 20, xxvi. p. 156.

the resolvability would be, in cases in which they are visible, seriously impaired. The presence of the framework of stars would account, Mr. Stone thinks, for their stability of form.

In the discussion which followed the reading of this note Professor Stokes stated, that in a star-cluster in which the component stars are surrounded by a luminous atmosphere, differences in distance from the eye will not alter the relative brightness of the stars and their atmospheres, unless we regard those atmospheres as of infinite extent. Mr. Huggins, in replying to Mr. Stone's note, added that unless we suppose the light which we receive from the sun itself to be but a fraction of that received from an imaginary atmosphere of enormous extent, we cannot entertain any doubt that the greater part of the light from a distant cluster must come from the stars composing it. Whilst acknowledging the accuracy of Mr. Stone's statement, that at a sufficient distance the light from a single star is insignificant compared with that from the cluster as a whole, he maintains that that distance must be so enormous that even the small solid angle subtended by the slit is sufficient to include a considerable number of stars, and that in that case Mr. Stone's argument loses its force. Moreover, Mr. Huggins maintained that this view is not compatible with the results of observation, because,

Firstly, he had not found the brightness of the bright lines and the continuing spectrum to stand to each other in the relation which we should expect from Mr. Stone's hypothesis.

Secondly, those clusters which the telescope can just resolve give no indication of bright lines.

Thirdly, the brightest line seems to be common to all nebulæ which yield a line spectrum, whereas we should expect the atmospheres, which Mr. Stone's theory supposes, to vary in composition, as do those of the fixed stars.

To these objections Mr. Stone replied[k], 1st. That he did not agree with Mr. Huggins with regard to the relative brightness of the lines and continuous spectrum. 2ndly.

[k] *Proc. Roy. Soc.*, 1877, xxvi. p. 517.

He thought the non-appearance of bright lines in the spectra of just resolvable nebulæ confirmatory of his view, as he had originally stated that the bright lines would not appear until the resolvability was seriously impaired. With regard to the third objection, he thought it quite as easy to imagine star-clusters of constant composition as isolated masses of gas.

Professor Stokes' objection he considered to be based upon a misunderstanding, since he regarded the atmospheres as not only optically but also physically continuous.

Mr. Lockyer[1] supported Mr. Stone, and said that he had looked for traces of an extensive chromosphere in *a* Lyræ (Viga) and other stars, and thought that he had seen traces of bright F and b lines.

Although the spectroscope has proved most valuable in establishing the distinction between true nebulæ and star-clusters, the subject is still beset with difficulties. The results of prismatic analysis have not always agreed with expectations. For instance, the spiral nebula 51 Messier, the form of which suggests a gaseous constitution, yields a continuous spectrum.

Mr. Huggins does not consider that objects which give continuous spectra are always star-clusters, for in some instances the mottled appearance of the spectrum suggests a different nature. True star-clusters give spectra of the same nature as those of single stars, except in a few cases in which the light is so faint that the dark lines cannot be discerned.

It does not seem possible to trace any connection between the nebulæ and the other heavenly bodies. The comets were at first thought by Mr. Huggins to be of common nature with them, but further observations have shewn that the head gives a spectrum identical with that of carbon, as seen in the combustion of olefiant gas, whilst the light from the tail is chiefly reflected sunlight.

The zodiacal light, which has been regarded as a nebulous atmosphere surrounding the sun, yields a continuous

[1] *Proc. Roy. Soc.*, 1878, xxvii. p. 50.

spectrum, and its light is probably due to the reflection of the sun's rays by cosmical dust.

The chemist finds here little basis for speculation. He is met at the outset by the uncertainty whether what he sees is the whole spectrum of the nebula, or whether other fainter lines have been lost in the passage through space. If he assumes that the four lines do indeed represent the total light, he has two alternatives before him. He may either regard the gases as existing in such a physical condition that these lines represent the complete spectra of the component elements, or he may suppose the matter of which they are composed to exist in a simpler condition than our terrestrial elements. The latter view is in accordance with Lockyer's theory of the dissociation of the elements in the sun and stars [m], which has recently received so much support from observations of sun-spot-spectra, in which certain iron lines were affected by the movements of the gas streams whilst others remained unaltered [n].

If, on the other hand, he regards the spectrum as incomplete, the absorptive power in space has robbed him of an unknown quantity of his material, and the hopelessly small residue is insufficient for any useful results.

That hydrogen, or some forerunner of hydrogen, is present in the nebulæ is rendered immensely probable by the coincidence of two of the nebula lines with two lines of that element. The presence of nitrogen is far less certain, for Mr. Huggins does not go further than to say that on the whole he is inclined to regard the brightest line as due to nitrogen. Of the nature of the substance which yields the second line no conjecture is possible.

The constancy of their constitution is the most striking chemical feature of the nebulæ. In no case has any line other than these four been found in the spectrum, and the nitrogen line, which is the brightest, is found in the spectra of all nebulæ which give indications of a gaseous constitution. This is the more remarkable, if the line be really due to nitrogen, from the fact that that substance has not been hitherto detected in the sun or fixed stars, which

[m] *Proc. Roy. Soc.*, xxviii. p. 157. [n] *Ibid.*, 1881, xxxi. p. 343.

seems to afford a strong argument against Mr. Stone's view of the nature of the nebulæ.

The presence of hydrogen will cause no surprise when we consider how widely that substance is distributed in the universe.

The observation of the spectra does not appear to lend any support to those theories which regard the nebulæ as the material from which suns are formed; for if by their gradual condensation the stars, which have apparently a far more complicated chemical constitution, are in course of formation, we should expect to find in the spectra of different nebulæ evidences of different degrees of complication, and not the remarkable uniformity which is actually observed.

Father Secchi [o], however, in whom Astronomy has recently sustained so great a loss, zealously supported Sir William Herschel's theory. He thought that in *a* Orionis, the spectrum of which contains no dark hydrogen lines, he saw an intermediate stage between nebula and star, the dark lines being here replaced by bright ones, and adds, "This theory has been confirmed, and, if I may say so, demonstrated by the discovery of gaseous nebulæ, and all things lead us to believe that these nebulæ will one day transform themselves into stars, and that all the stars which shine have had such an origin."

Since to obtain spectra analogous to that given by this cosmical matter we must have recourse to the most energetic means of dissociation at our disposal, such as the induction-spark intensified by a condenser, Secchi thought the matter of which the nebulæ are composed must be in an extremely elementary condition.

It is interesting, in connection with this point, to consider that some source of energy must be found to compensate the continual loss of energy which they suffer by radiation, and that which naturally suggests itself to the mind is a condensation of the gaseous mass.

The spectroscope, besides giving us an insight into the

[o] *Le Soleil*, p. 400.

chemical constitution of a gaseous mass, enables us to form some idea of its physical condition.

Mr. Huggins concluded that the tension of the gas might be slightly greater than that in a Geissler's tube, and shewed that in this case the nitrogen spectrum is reduced to a single line.

Messrs. Frankland and Lockyer have confirmed this result, and have shewn that the same holds good for hydrogen [p].

Zöllner [q] considers that the temperature must be comparatively low, whilst in Geissler's tubes it is high.

Secchi [r], however, finding that the bright line of the nebula is coincident with a dark line in the nitrogen spectrum of the first order, and a bright line in that of the second, which latter is produced by an electric spark of high tension, concluded that the nitrogen was in the same state as terrestrial nitrogen through which such a spark is passing. Wöllner also ascribes to them a high temperature.

M. Planté [s] has attempted to explain the spiral character of some nebulæ by electrical action. He speaks as follows:—

"The gyratory movements, coupled with luminous effects which I have observed accompanying a powerful discharge of dynamical electricity, and the spherical and annular forms manifested by the bodies submitted to this action, have led me to admit the probability of the electrical origin of heavenly bodies. I believe that it is possible to attribute such an origin to those worlds in course of aggregation or disintegration which constitute the irresolvable nebulæ, and particularly to those which affect the remarkable form of spirals."

Many other astronomers have from time to time devoted their attention to the nebulæ, and amongst these must be mentioned the names of Schönfeldt, Argelander, Schmitz, Oppölzer, and Vogel.

We have now followed our subject down to the present day, but the goal seems still as far off as ever, much further,

[p] *Proc. Roy. Soc.*, xvii. 288, 453, and xviii. 79.

[q] *Sulla grande Nebulosa di ⊖ Orione. Firenze. Stamperia Reale*, 1868, p. 29.

[r] *Ueber das Nordlichtspectrum. Ber. d. Sächs Ges. d. Wiss.*, Oct. 31, 1870.

[s] *Comptes Rendus*, lxxxi. p. 749.

indeed, than when the stellar theory seemed to bring the nebulæ into the same category with the star-clusters, which offer no such difficult problem for the solution of astronomers; but we may fairly expect that the never-ceasing advance of knowledge will in time dispel many of the difficulties which surround the subject, and will enable us to form a more satisfactory conception of the nature of these objects, which must always possess the greatest interest for all who pursue the glorious science of the stars.

Printed by Parker and Co., Crown Yard, Oxford.